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ADDITIONAL ANALYSES OF PROBABILITY OF DETECTION (POD) IN SEARCH AND RESCUE (SAR) PROJECT DATA

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This report is the fifteenth in a series which documents the Improved Probability of Detection in Search and Rescue (POD/SAR) Project at the USCG R&D Center.

16. Abstract

This report assesses the search performance of Coast Guard units employing both visual and electronic sensors in detecting small boats (16 to 21 feet) and life rafts. A comparison is also made between real-time search performance and post-search videotape analysis for a prototype Coast Guard forward-looking infrared (FLIR) system.

Based upon data collected during eight experiments, lateral range curves and sweep width estimates are developed for combined surface vessel radar (SVR)/visual and side-looking airborne radar (SLAR)/visual searches. This analysis demonstrates that, in many situations, combined sensor search is significantly more effective than single-sensor search. The FLIR analysis demonstrated that human factors can degrade the present FLIR system's detection capability.

Combined sensor search guidance is recommended and suggestions for further data collection and analysis are made.

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Search and Rescue, Multisensor Search, Visual Search, Electronic Search, Infrared, FLIR, Radar, SLAR, Probability of Detection, Surface Target Detection

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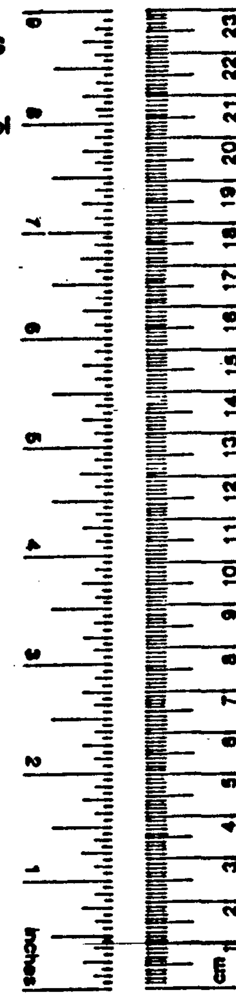
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

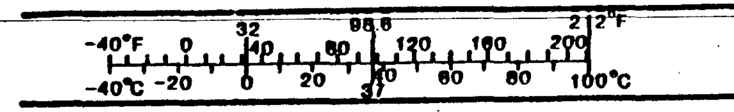
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square cenilmeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286. Units of Weights and Measures. Price $2.25. SD Catalog No. C13.10.286.



Approximate Conversions from Metric Measure

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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INTRODUCTION

1. Purpose of Report

Data collected by the U.S. Coast Guard Research and Development Center (R&D Center) during visual and electronic detection experiments have been further analyzed to provide search performance estimates for combined surface vessel radar (SVR)/visual and side-looking airborne radar (SLAR)/visual searches. Videotapes of forward-looking infrared (FLIR) searches have been analyzed to estimate the amount of detection performance degradation that occurs due to the human operator during this type of search. The results of these analyses are presented in this report.

2. Background

Since 1978, the Coast Guard Research and Development Center (R&D Center) has conducted eight experiments designed to evaluate the detection performance of Coast Guard visual lookouts and electronic sensors. These experiments were part of the Improved Probability of Detection (POD) in Search and Rescue (SAR) Project being conducted by the Coast Guard to improve search planning guidance in the National Search and Rescue Manual. Eleven reports have been prepared documenting the performance of visual scanners, surface vessel radars (SVRs), side-looking airborne radar (SLAR), and a prototype forward-looking infrared system (FLIR) in detecting common search and rescue targets such as persons in water (PIWs), 16- and 41-foot boats and 4- to 7-man life rafts.

The additional analyses documented in this report will provide search planners with empirically derived detection performance estimates for combined sensor search and an estimate of the human operator factors involved in the FLIR detection process.

3. Electronic Sensor Descriptions

The AN/APS-94D SLAR, as configured in the Coast Guard Airborne Oil Surveillance System (AOSS), was used to represent the SLAR detection capability when SLAR/visual sweep widths were computed. Two Coast Guard surface search/navigation radars were treated in the SVR/visual search performance analysis: the AN/SPS-64(V) (installed aboard WPB- and WMEC-class Coast Guard cutters) and the AN/SPS-66 (installed aboard 41-foot UTBs). A prototype FLIR system, developed by Northrop Corporation for the Coast Guard and installed aboard an HH-52A helicopter, was used during the FLIR searches.

RESULTS

1. Combined Sensor Search Performance

Table 2-1 and tables 2-3 through 2-6 in the main body of this report present sweep width estimates for combined SLAR/visual and SVR/visual search in a variety of environmental conditions. A listing of assumed SLAR/visual search parameter values is given on page 2-8. Table 2-2 lists search parameter values assumed for SVR/visual searches.

Representative lateral range curves for both types of combined sensor search are given in the main body of this report.

2. FLIR Operator Factors

From a total of 167 detection opportunities, which occurred during the successfully videotaped FLIR searches, 115 real-time detections were made by the FLIR operators and 120 detections were made by a post-experiment video analysis team. The post-analysis team made the 115 detections common to both groups an average of 4.8 seconds earlier than the FLIR operators did. This translates to an average increase in detection range of just under 0.1 nautical mile at the assigned 60-knot ground speed.

These data were sorted into target type and significant wave height categories to determine how these parameters influenced performance differences. Table 3-1 in the main body of this report summarizes the resulting statistics of interest.

CONCLUSIONS

- o Visual scanners are capable of supplementing SLAR search by filling in a "blind zone" that occurs directly beneath the AOSS aircraft due to antenna geometry. SLAR sweep widths are not substantially improved by visual scanners, but more uniform search area coverage is achieved.

- o The relative contribution of SVR and visual scanners in a combined sensor search varies a great deal with environmental conditions. Combined SVR/visual sweep width estimates can be much higher than those for either sensor alone if both sensors make a substantial, but not highly dominant, contribution to search platform detection capability.

- o Data presented in Table 3-1 of this report suggest some FLIR detection performance degradation due to human operator limitations. The limited nature of the present FLIR data base renders this conclusion tentative pending further testing with a wider variety of operators and environmental conditions.

RECOMMENDATIONS

- o Combined sensor searches should be planned to favor the sensor that makes a more dominant sweep width contribution in existing environmental conditions.

- o Limited field experiments should be conducted to validate the combined sensor sweep width estimates given in this report.

- Lateral range curves for combined sensor searches should be input to the Coast Guard Computer-Assisted Search Planning (CASP) model so that base PODs similar to those given in Reference 13 can be generated.

- Sweep width estimates, base PODs, and search conduct guidance for combined sensor searches should be incorporated into the National SAR Manual.

- If additional investigation of human factors in the FLIR detection process is undertaken, time on task, environmental conditions, target type, and operator training level should be included as parameters of interest.

CHAPTER 1
BACKGROUND

1.1 INTRODUCTION

Since 1978, the Coast Guard Research and Development Center (R&D Center) has conducted eight experiments designed to evaluate the detection performance of Coast Guard visual lookouts and electronic sensors. These experiments were part of the Improved Probability of Detection (POD) in Search and Rescue (SAR) Project being conducted by the Coast Guard to improve search planning guidance in the National Search and Rescue Manual (Reference 1). Eleven reports (References 2 through 12) have been prepared documenting the performance of visual scanners, surface vessel radars (SVRs), side-looking airborne radar (SLAR), and a prototype forward-looking infrared system (FLIR) in detecting common search and rescue targets such as persons in water (PIWs), 16- and 41-foot boats and 4- to 7-man life rafts. Extensive data bases have been compiled for visual and SVR sensors, and more limited data are available for SLAR and FLIR.

This report will present two additional analyses of the data described above. First, combined sensor detection performance estimates for visual/SLAR and visual/SVR searches will be discussed. Second, a comparison of real-time FLIR search detection performance to that achieved during post-experiment analysis of searches recorded on videotape will be made. The first analysis provides Coast Guard search planners with inputs that are usable immediately. The second analysis, based on very limited data, provides an estimate of the degree to which FLIR detection performance can be expected to degrade as a result of the human operator. This information should be useful in developing a comprehensive FLIR detection model in the future.

1.2 MEASURES OF SEARCH PERFORMANCE

The primary performance measure currently utilized by SAR mission coordinators to plan searches is sweep width (W). Sweep width is a single number summation of a more complex range/detection probability relationship. Mathematically,

$$\text{Sweep Width (W)} = \int_{-\infty}^{\infty} P(x)dx,$$

where

x = lateral range or closest point of approach (CPA) to targets of opportunity (see Figure 1-1) and

P(x) = probability of detection at lateral range x.

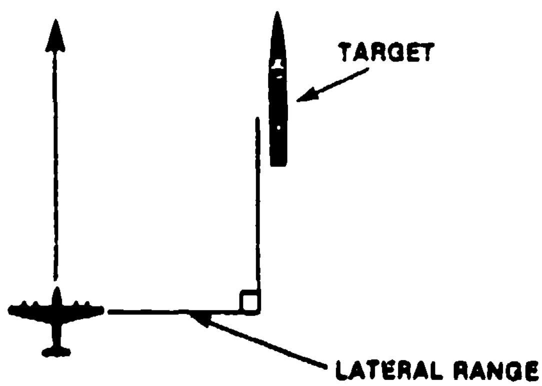

Figure 1-1. Definition of Lateral Range

Figure 1-2 shows a typical P(x) curve as a function of lateral range. In Figure 1-2, (x) is the lateral range of detection opportunities.

In concept, sweep width is the numerical value obtained by reducing the maximum detection distance of any given sweep through a search area so that scattered targets which may be detected beyond the limits of W are equal in number to those which may be missed within those limits. Figure 1-3 (A and B)

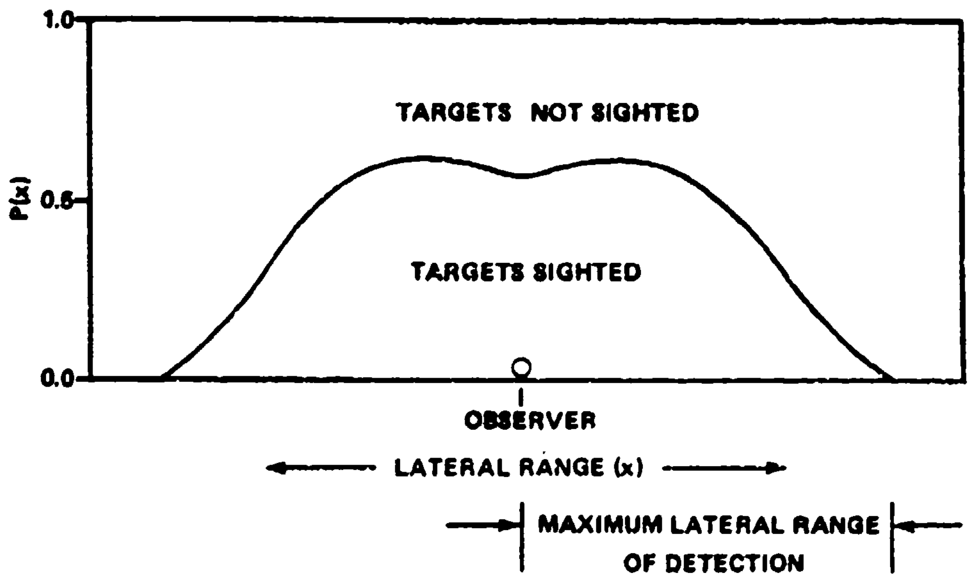

Figure 1-2. Relationship of Targets Sighted to Targets Not Sighted

graphically presents this concept of sweep width. The number of targets missed inside the sweep width distance is indicated by the shaded portion near the top middle of the rectangle (area A) while the number of targets sighted beyond the sweep width distance out to maximum detection range (R_D) is indicated by the shaded portion at each end of the rectangle (area B). Referring only to the shaded areas, when the number of targets missed equals the number of targets sighted (area A = area B), sweep width is defined. A detailed mathematical development and explanation of sweep width can be found in Koopman (Reference 13).

SAR Manual (Reference 1) search effectiveness estimates use sweep width (W) and search pattern track spacing (S) to define a quantity called coverage factor (C), with C = W/S. A relationship exists between the cumulative probability of detection (POD)* for a search, the shape of the lateral range curve for a given search scenario, and C which enables the search planner to predict

*It is important to appreciate the difference between P(x) and POD. P(x) is the probability density function describing the probability on one sweep of detecting a target with a lateral range x from the searcher, while POD is the cumulative probability that a randomly distributed target in a given search area will be detected at least once during a uniform search of the area.

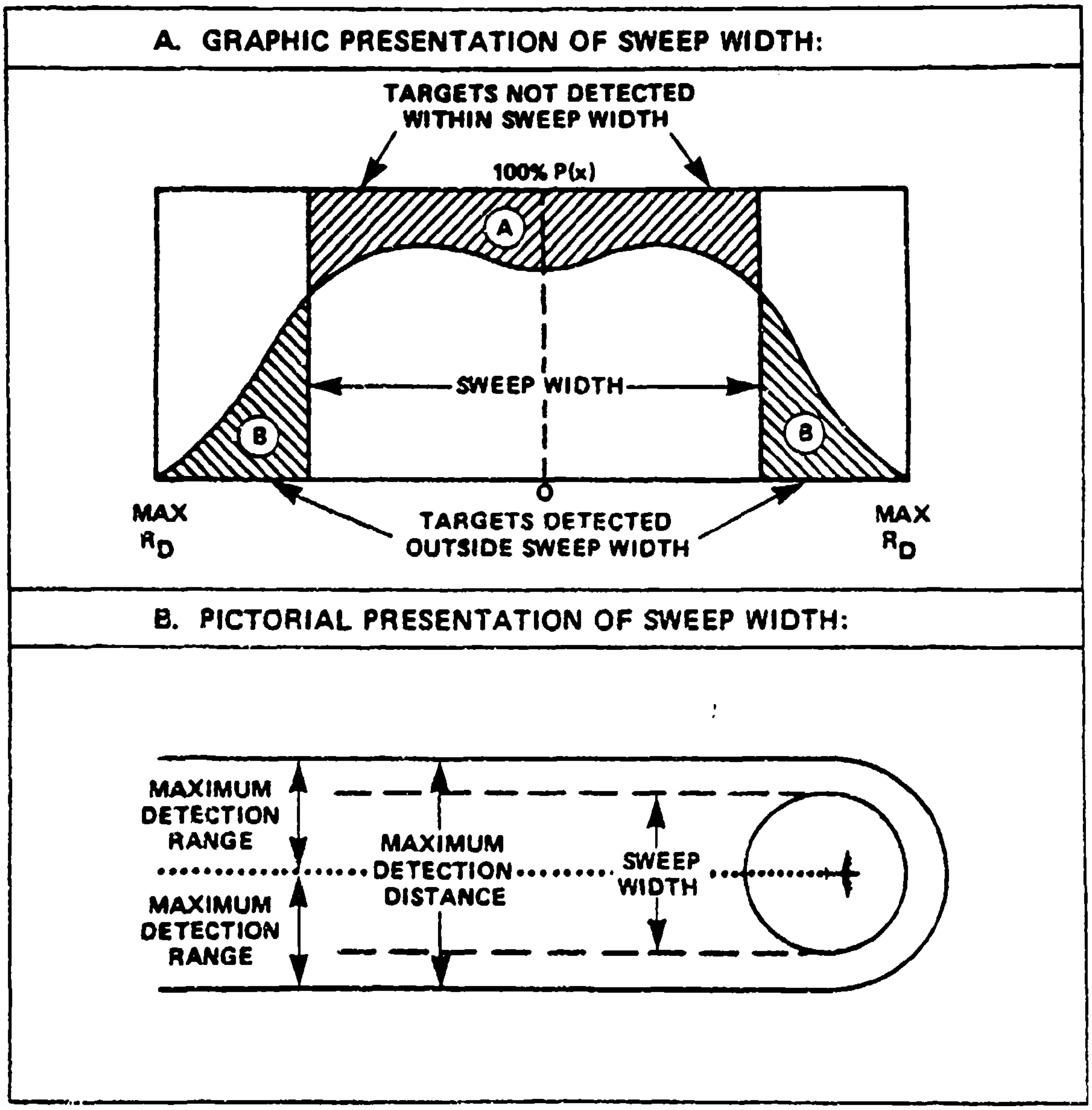

Figure 1-3. Graphic and Pictorial Presentation of Sweep Width

overall search performance (Reference 14). The key element in POD prediction is the lateral range curve. Once the lateral range curve has been determined for a given search scenario, W and POD can be determined.

1.3 DESCRIPTION OF AVAILABLE DATA

1.3.1 Visual Detection Data

Of the four sensor types discussed in this report, the human lookout/scanner has been the most studied during the POD in SAR Project. References 2, 3, 5, and 8 describe in detail the search units, targets, and environmental conditions for which visual detection data have been compiled. Table 1-1 summarizes the range of environmental conditions* represented in the visual detection data base, which consists of a total of 4916 target detection opportunities. Coast Guard helicopters, fixed-wing aircraft, utility boats (UTBs), and cutters (WPBs, WMECs) dedicated nearly 948 hours of search time to this data collection effort during seven of the eight Project experiments.

Analysis of these data has resulted in the development of multivariate statistical models which utilize information concerning search unit, target, and environmental characteristics to generate lateral range curves for a wide range of search scenarios.

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*In previous POD/SAR project reports, ocean wave height as observed by experiment participants has been referred to as "swell height." Beginning with this report, the term "significant wave height" will replace "swell height." The reasons for this change are best summarized by the following sentences taken from Reference 15, pp 112: "The most commonly used representative wave is $H_{.33}$ or the average height of the upper third of the waves. This is called the significant wave height H_s and it is approximately the height an experienced observer will give when visually estimating the height of waves at sea." Search units almost always depend upon visual observations to estimate sea conditions; thus, this new terminology has been adapted as more descriptive and universally understood.

Table 1-1. Range of Environmental Conditions Represented in Visual Detection Data Base

SRU TYPE	TARGET TYPE	RANGE OF ENVIRONMENTAL CONDITIONS		
		VISIBILITY (nm)	WIND SPEED (knots)	SIGNIFICANT WAVE HEIGHT (ft)
Surface Craft	16-foot boats	3-20	0-25	0-5
	Life rafts	1-18	0-19	0-3
	PIWs	2-20	0-21	0-5
	41-foot boats	10-15	4-17	1-3
Aircraft	16-foot boats	3-20	0-20	0-3
	Life rafts	4-15	0-30	0-4
	PIWs	4-15	0-22	0-3
	41-foot boats	12-15	10-18	2-3

1.3.2 Side-Looking Airborne Radar Data

SLAR data were collected during four of the eight Project experiments. Two configurations of the AN/APS-94 SLAR were tested: the conventional Airborne Oil Surveillance System (AOSS) model and a NASA-developed SLAR/radar image processor (SLAR/RIP) prototype system which provided digital image enhancement capabilities. Only the AOSS configuration of the SLAR is deployed operationally, so this report will use detection models developed through analysis of the 1216 detection opportunities obtained with that system. The SLAR/RIP system, while shown to perform better than AOSS in detecting SAR targets, does not represent the present-day capability of Coast Guard SLAR. Two new SLARs, the AN/APS-131 and AN/APS-135, are scheduled to become operational in the near term and will likely be evaluated during future Project experiments. Due to basic similarities, the SLAR/visual detection performance achievable with these new systems should be similar to that predicted for the AOSS SLAR system in this report.

The range of environmental conditions encountered during the AOSS SLAR tests is given in Table 1-2. Target types tested include 16- to 21-foot fiberglass or aluminum boats with metal equipment (engine, gas tank, etc.), 13-to 18-foot fiberglass boats without equipment, and life rafts without radar reflectors. The reader should note that all SLAR data collected thus far have been reconstructed from post-experiment analysis of film and videotape imagery. Therefore, the present SLAR detection models developed from these data may not represent real-time operational search capability. References 4, 6, and 10 provide detailed discussions of the SLAR experiments and detection model development.

1.3.3 Surface Vessel Radar Data

SVR data were collected during three of the eight Project experiments. The range of environmental conditions encountered during the SVR experiments is shown in Table 1-3. Two Coast Guard surface search/navigation radars were tested: the AN/SPS-66 (installed aboard 41-foot UTBs and some 95-foot WPBs) and the AN/SPS-64(V) (installed aboard 82-foot WPBs).

The three experiments (References 7 and 9) were designed as system performance tests so that an upper bound on the detection capability of the AN/SPS-64(V) and -66 radars could be determined. Two types of SVR searches were conducted: detection runs and tracking runs (References 9 and 16). A total of 393 detection runs and 207 tracking runs (described below) were conducted. Small boats and life rafts with and without radar reflectors were used as search targets.

The objective of the detection runs was to collect data for developing cumulative detection probability (CDP) versus range curves for each radar/target type combination tested. For the detection runs, the operators were semi-alerted; that is, they had some knowledge of where and when to expect radar contacts to occur.

Table 1-2. Range of Parameters Investigated During AOSS SLAR Experiments

TARGET TYPE	LATERAL RANGE (nm)	ALTITUDE (ft)	VISIBILITY (nm)	WIND SPEED (knots)	SIGNIFICANT WAVE HEIGHT (ft)	ANTENNA POLARIZATION	PRECIPITATION	RELATIVE HUMIDITY (%)	WAVE DIRECTION (relative to beam)
Life rafts	0-27	500-5500	1-15	3-30	0.5-3	Vertical and horizontal	Clear Fog Rain	59-100	Perpendicular Parallel
Small boats	0-27	1000-5500	1-15	3-17	0.5-4	Vertical and horizontal	Clear Rain	55-100	Perpendicular Parallel
41'-95' Coast Guard vessels	0-27	1000-5000	1-15	3-12	0.5-4	Vertical and horizontal	None	55-100	Perpendicular Parallel

Table 1-3. Range of Environmental Parameters Encountered During SVR Experiments

PARAMETER OF INTEREST	DETECTION RUNS		TRACKING RUNS	
	MINIMUM VALUE	MAXIMUM VALUE	MINIMUM VALUE	MAXIMUM VALUE
Wind Speed (knots)	0	16	0	23
Significant Wave Height (ft)	0	4	0	4.5
Precipitation	None	Fog/rain	None	Rain
Relative Humidity (%)	39	100	43	95

Tracking runs were conducted to collect blip/scan ratio data. The blip/scan ratio is an estimate of the instantaneous probability that radar will detect a target at a given range. For the tracking runs, radar operators were fully alerted; that is, they had accurate knowledge of target range and bearing.

Knowing the blip/scan ratio and CDP for a given radar/target type combination at various ranges facilitated the development of lateral range curves representative of Coast Guard radar detection performance in clear weather (Reference 16).

Experiment data were also used to estimate the range (R_p) at which the radars had an instantaneous probability (P) of detecting a given target. This range was used along with other radar and environmental parameters in the radar range equation to calculate target radar cross sections. These radar cross sections have been calculated (Reference 9), and radar detection performance estimates will be extrapolated in this report to environmental conditions not present in the experiment data base. Discussion of the radar range equation and specific parameter values for the AN/SPS-64(V) and AN/SPS-66 radars can be found in Reference 17. Additional discussion of the radar range equation and calculation of target cross section can be found in Reference 18.

1.3.4 FLIR Data

Limited testing of a prototype Coast Guard FLIR system was conducted during the fall 1981 electronic detection experiment (Reference 11). Small boats, life rafts, and simulated PIW targets were used during these tests. Data were collected during both daylight and night searches. The range of environmental parameters encountered is shown in Table 1-4. A total of 493 detection opportunities occurred during the FLIR searches, and 167 of these were recorded on videotape.

Table 1-4. Range of Environmental Parameters Encountered During FLIR Experiment

PARAMETER OF INTEREST	MINIMUM VALUE	MAXIMUM VALUE
Wind Speed (knots)	3.	22.
Significant Wave Height (ft)	0.	3.5
Surface Air Temperature (°C)	11.	23.
Surface Water Temperature (°C)	12.8	14.7
Cabin Temperature[1] (°C)	11.	19.
Relative Humidity on Surface (%)	53.	82.
Relative Humidity in Cabin[1] (%)	47.	70.
Meteorological Visibility (nm)	5.	18.
Cloud Cover (%)	0.	90.

[1]The cabin was exposed to outside air and warmed only by avionics/electronics heat dissipation.

The FLIR searches were rigidly controlled system performance tests with fields of view, depression angles, and azimuthal scanning restricted to a straight-ahead direction (all targets were set along assigned search tracklines). Thus, the limited existing data base may not be representative of operational search capability, but only of system detection capability in a tightly controlled, alerted-operator test scenario.

1.4 ANALYSIS APPROACH

Two types of combined sensor search are treated in this report: SLAR/visual and SVR/visual. As discussed in Section 1.3, the visual detection data base is extensive enough for a visual detection model to have been developed which covers a broad range of targets (PIWs to 41-foot boats) and environmental conditions. SLAR data have been collected only in good-to-moderate

conditions, so estimates of SLAR/visual search performance were confined to those environmental conditions common to both data bases. SVR data demonstrated that, with 16-foot boat and life raft targets, radar detection performance deteriorated rapidly in seas greater than 2 feet. Given this effect, SVR/visual search performance was evaluated primarily for environmental conditions represented by seas of 2 feet or less. The radar range equation facilitated estimation of SVR lateral range curves for some environmental conditions not present in the SVR data base (rain, snow, fog). Combined SVR/visual lateral range curves for clear weather were developed from empirical SVR detection data and the visual detection models. Additional SVR/visual lateral range curves were developed from extrapolated SVR performance estimates and the visual detection models.

The limitations of the existing FLIR data base preclude development of lateral range curves at present. Videotaped search data were used, however, to estimate the degree to which detection performance was degraded (in the system as presently configured) by human operator limitations.

1.4.1 Independence of Sensors

In developing performance estimates for combined sensor search, it was necessary to consider the extent to which operation of one sensor affected the performance of another. A related issue was the degree of similarity (correlation) between the responses of paired sensors to variations in environmental and target-related parameters.

The assumption made relative to the first question was that beneficial effects (for example, a questionable radar contact alerting visual lookouts to the presence of a target when neither sensor alone might have detected it) and detrimental effects (for example, questionable visual contact reports causing the radar operator to concentrate on only a small portion of his display, reducing total radar area coverage) probably cancelled each other. Operational experience during the experiments provided no basis for refuting this subjective judgment.

The second question, that of correlation between the performance of two sensors, had a direct impact upon the manner in which detection probabilities were to be combined to generate multisensor lateral range curves. This question was addressed differently for SLAR/visual searches than for SVR/visual searches. There is only a small region of overlap between the area effectively searched by visual scanners in a fixed-wing aircraft and that searched by AOSS SLAR. Also, over the range of environmental parameters treated in the report, the SLAR detection models developed from experiment data do not predict significant variation in search performance, while the visual detection model for fixed-wing aircraft does predict substantial performance variations. Consequently, complete independence of the SLAR and visual sensors was assumed. In the case of SVR/visual search, the two sensors typically overlap a great deal in their effective lateral range coverage. Both sensors demonstrated a sensitivity to variations in environmental parameters, such as significant wave height and wind speed, over the range of values represented in the data. These similarities in environmental effects on detection performance suggested that some sensor correlation could justifiably be assumed when generating combined SVR/visual lateral range curves. Ultimately, it was decided to compute two sets of SVR/visual lateral range curves and sweep widths. One set of curves and sweep widths assumed complete sensor independence. The other set averaged results obtained by assuming complete correlation with those obtained by assuming complete independence of the two sensors. Section 1.4.3 discusses the computational methodology employed to obtain the combined sensor detection probabilities.

1.4.2 Extrapolation of SVR Search Data

In addition to the clear-weather environmental conditions represented in the empirical SVR data base, rain, snow, and fog conditions were included in this analysis by using the radar range equation to extrapolate performance estimates. Extrapolation was confined to cases where seas were assumed to be 2 feet or less because analyses presented in Reference 9 demonstrated that Coast Guard SVR detection performance with small boat and life raft targets deteriorates rapidly in seas greater than 2 feet.

The process of extrapolating SVR detection performance estimates to rain, snow, and fog conditions required making many assumptions and a great deal of computation. The most important steps in the process are described below.

A. A variety of precipitation/fog conditions were selected for extrapolation. For each case, atmospheric attenuation factors in (dB/nm) were obtained from References 17 and 19. Detection range reduction due to storm clutter (Reference 17) was then calculated for ranges at which expected instantaneous detection probabilities were .20, .15, .10, .05, and .01. Probabilities were restricted to these values for two reasons: first, empirical data collected in clear weather demonstrated that instantaneous detection probabilities seldom exceeded these values with small targets, and second, this range of probabilities was sufficient to define the shape of an instantaneous detection probability versus range curve for each situation of interest. In all cases, it was assumed that storm clutter could be kept to a tolerable level without eliminating target echoes completely. Tables 1-5 and 1-6 summarize the results of these calculations. Assumed false alarm probabilities (P_{FA}) used in the calculations are listed for each type of precipitation.

B. Instantaneous detection probability versus range was calculated for each set of conditions using the radar range equation. This process required a great deal of subjective intervention because theoretical calculations alone would allow one to predict unreasonably high detection probabilities at close range. Empirical data did not support using detection probability values of greater than ~.45 for a target with a radar reflector in light precipitation (based on comparison with data collected in clear, calm conditions) and ~.10 for a target without a radar reflector in heavy precipitation (based on comparison with data collected in clear weather with 2-to 4-foot seas). Figure 1-4 is an example of the instantaneous detection probability versus range curves generated during this phase of the analysis. References 17, 18, and 20 provide detailed information on

Table 1-5. Calculated Atmospheric Attenuation and Range Reduction Due to Clutter in Various Forms of Precipitation (AN/SPS-64(V) Radar)

ENVIRONMENTAL CONDITIONS (Seas $\leq$ 2 ft)	INSTANTANEOUS DETECTION PROBABILITY	TWO-WAY ATMOSPHERIC ATTENUATION L_{at} (dB/nm)	PERCENT OF CLEAR-WEATHER RANGE REMAINING IN STORM CLUTTER	
			TARGET WITH REFLECTOR	TARGET WITHOUT REFLECTOR
LIGHT RAIN (1 mm/hr) $P_{FA} \cong 10^{-3}$	.20	1.17×10^{-1}	95	83
	.15		95	84
	.10		95	85
	.05		96	87
	.01		97	90
MODERATE RAIN (4 mm/hr) $P_{FA} \cong 10^{-3}$	.20	4.62×10^{-1}	59	42
	.15		60	42
	.10		62	43
	.05		64	45
	.01		68	49
HEAVY RAIN (16 mm/hr) $P_{FA} \cong 10^{-1}$	.20	1.85	29	20
	.15		31	21
	.10		33	22
	.05		N/A	N/A
	.01		N/A	N/A
MODERATELY HEAVY SNOW (wet ~ 0° C) (4 mm/hr of H_2O; 1.5 in./hr of snow) $P_{FA} \cong 10^{-1}$	.20	Negligible	37	26
	.15		39	27
	.10		42	29
	.05		N/A	N/A
	.01		N/A	N/A
DENSE FOG (100-ft visibility) $P_{FA} \cong 10^{-3}$	ALL	.44 @ 15°C	~100	~100

Table 1-6. Calculated Atmospheric Attenuation and Range Reduction Due to Clutter in Various Forms of Precipitation (AN/SPS-66 Radar)

ENVIRONMENTAL CONDITIONS (Seas $\leq$ 2 ft)	INSTANTANEOUS DETECTION PROBABILITY	TWO-WAY ATMOSPHERIC ATTENUATION L_{at} (dB/nm)	PERCENT OF CLEAR-WEATHER RANGE REMAINING IN STORM CLUTTER	
			TARGET WITH REFLECTOR	TARGET WITHOUT REFLECTOR
LIGHT RAIN (1 mm/hr) $P_{FA} \cong 10^{-3}$	.20 .15 .10 .05 .01	1.17×10^{-1}	94 94 95 95 96	81 82 83 85 87
MODERATE RAIN (4 mm/hr) $P_{FA} \cong 10^{-3}$	.20 .15 .10 .05 .01	4.62×10^{-1}	57 58 59 61 65	39 40 42 43 46
HEAVY RAIN (16 mm/hr) $P_{FA} \cong 10^{-1}$	.20 .15 .10 .05 .01	1.85	28 29 31 N/A N/A	19 20 21 N/A N/A
MODERATELY HEAVY SNOW (wet ~ 0° C) (4 mm/hr of H_2O; 1.5 in./hr of snow) $P_{FA} \cong 10^{-1}$	.20 .15 .10 .05 .01	Negligible	35 37 40 N/A N/A	24 25 27 N/A N/A
DENSE FOG (100-ft visibility) $P_{FA} \cong 10^{-3}$	ALL	.44 @ 15°C	~100	~100

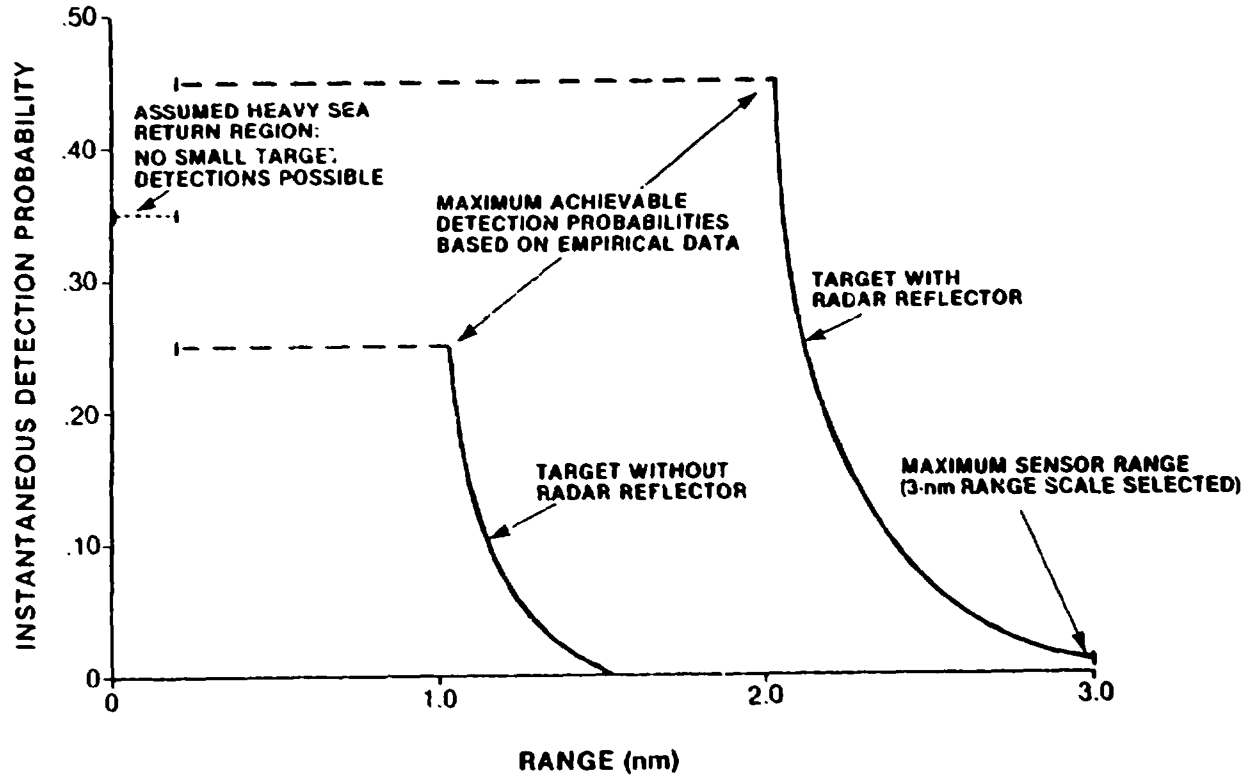


Figure 1-4. Estimated Instantaneous Detection Probabilities for AN/SPS-64(V) Radar Searching in Dense Fog (100-ft visibility) at 15°C (Seas ≤ 2 ft)

use of the radar range equation and were the primary references used for this analysis.

C. SVR lateral range curves were generated by integrating the instantaneous detection probabilities obtained in Step B. The following relation, adapted from Reference 16, was used for this purpose:

$$P(x) = 1-e^{-c\sum_{y=0}^{y=\sqrt{R_m^2 - x^2}} P_{(\sqrt{y^2 + x^2})}\Delta y}$$

where:

$P(x)$ = probability of detecting a target that closes to lateral range x along a path parallel to the search vessel's track,

c = a multiplicative factor used to bring theoretical predictions as close as possible to results of empirical data analysis (The value of c was determined for each radar/target type combination by comparing the lateral range curves predicted for clear weather using the method described in this report with those derived from empirical data presented in Reference 9. Values of c ranged from 1.4 to 2.1.),

y = range from target to CPA along a line parallel to search vessel track,

R_m = selected maximum sensor range (assumed to be 3 nautical miles for this analysis) and,

$P_{(\sqrt{y^2+x^2})}$ = "instantaneous" probability of detection at range $r = \sqrt{y^2 + x^2}$.

Figure 1-5 depicts these quantities graphically. By repeating this integration for a number of lateral ranges from 0 to maximum sensor range, probability of detection versus lateral range curves were generated for each data group of interest.

1.4.3 Computation of Combined Sensor Detection Probabilities

When it is assumed that two sensors search independently of each other, the combined probability of detection for both at lateral range x is given by:

$$P(x)_{COMBINED} = 1-[(1-P(x)_A)]\ [(1-P(x)_B)]$$

where:

$P(x)_A$ = probability of detection by sensor A at lateral range x and

$P(x)_B$ = probability of detection by sensor B at lateral range x.

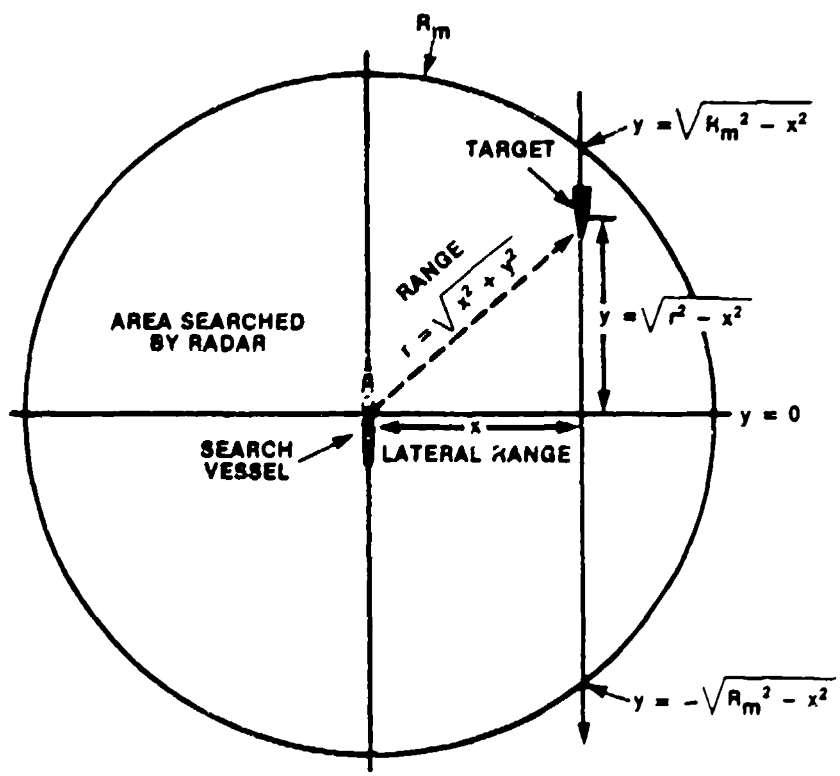


Figure 1-5. Searcher-Target Interaction at Lateral Range x

CHAPTER 2
COMBINED SENSOR SEARCH PERFORMANCE

2.1 INTRODUCTION

Section 2.2 presents combined SLAR/visual lateral range curves and sweep widths for six different search scenarios. Recommendations for conducting SLAR/visual search are also included. Section 2.3 presents a representative number of SVR/visual lateral range curves and complete sweep width tables for all search scenarios analyzed. Recommendations for SVR/visual search conduct and a discussion of which environmental conditions favor this type of search are also given.

2.2 SLAR/VISUAL SEARCH PERFORMANCE

2.2.1 Lateral Range Curves and Sweep Widths

Figures 2-1 through 2-6 are combined SLAR/visual lateral range curves for two sets of weather conditions and three target types. The two sets of weather conditions chosen characterize upper and lower bounds represented in the AOSS SLAR data base. The visual detection curves are for fixed-wing aircraft search based upon data collected using HU-16, HC-131, and HC-130 Coast Guard units. The AOSS SLAR is currently deployed in a Coast Guard HC-130.

The terms "good" and "fair" are used on the figures to represent the following sets of search parameters:

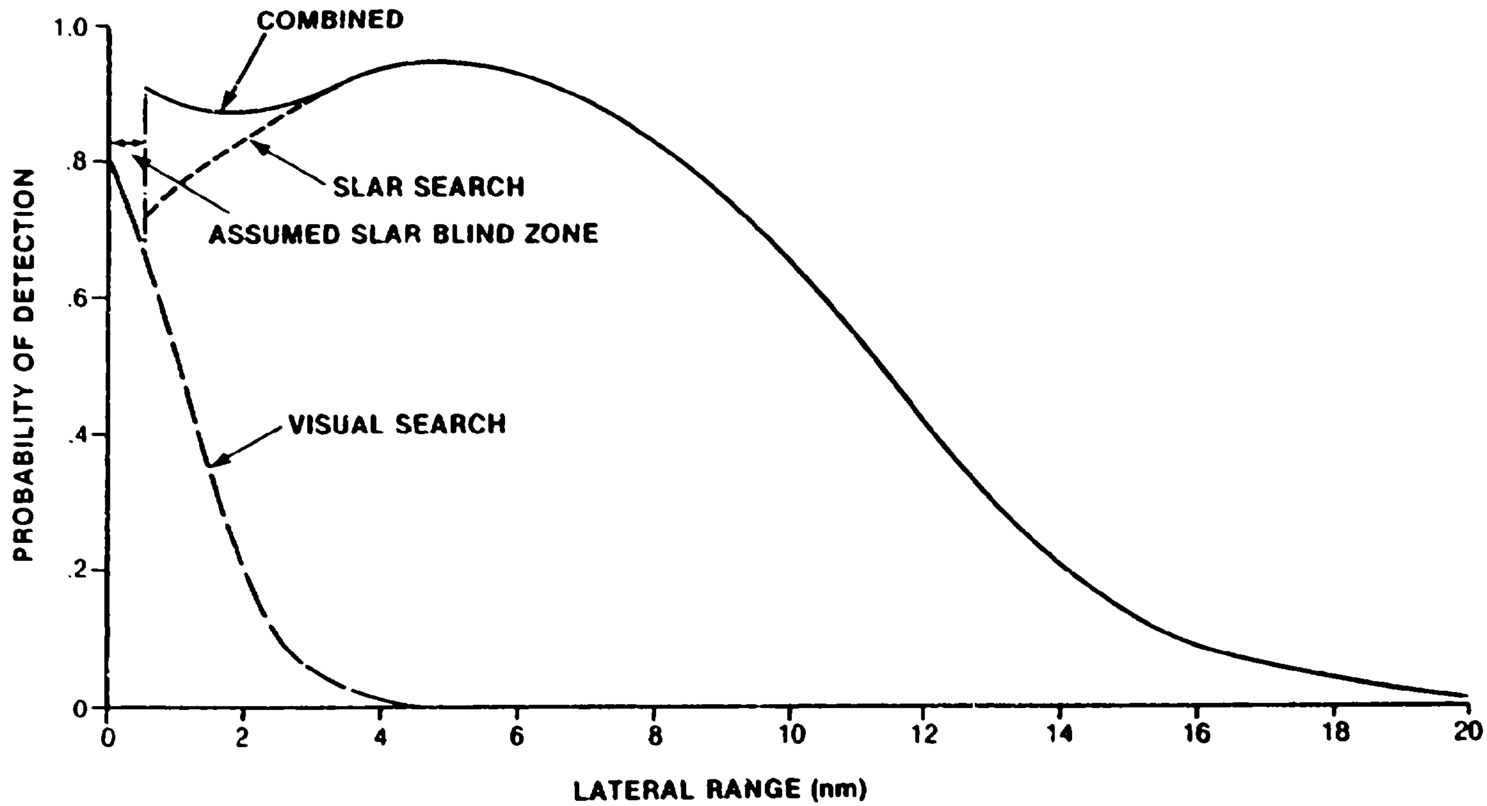


Figure 2-1. AOSS SLAR/Visual Search Performance in Good Conditions; Fully Equipped 16- to 21-Foot Fiberglass Boat Target

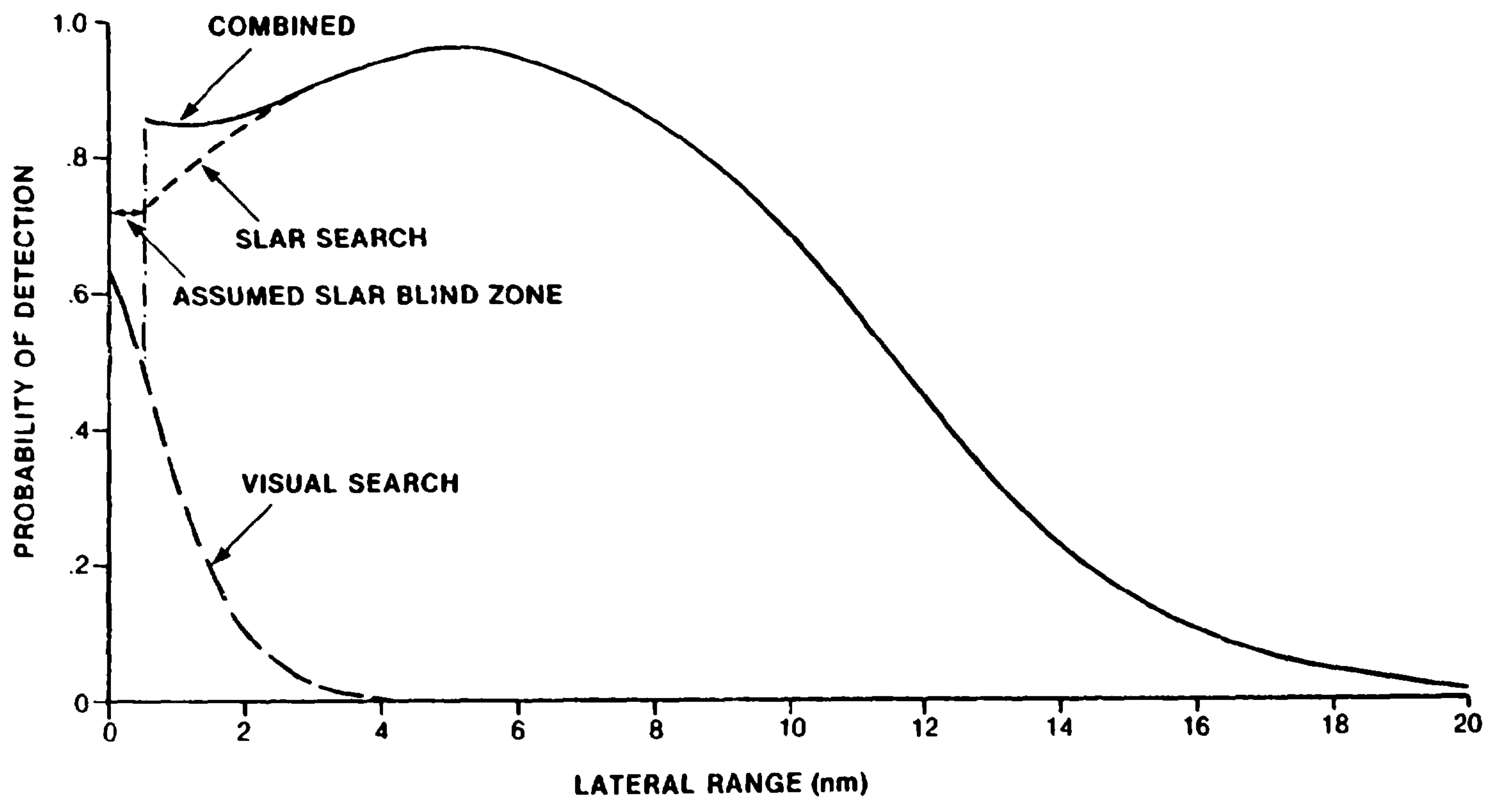


Figure 2-2. AOSS SLAR/Visual Search Performance in Fair Conditions; Fully Equipped 16- to 21-Foot Fiberglass Boat Target

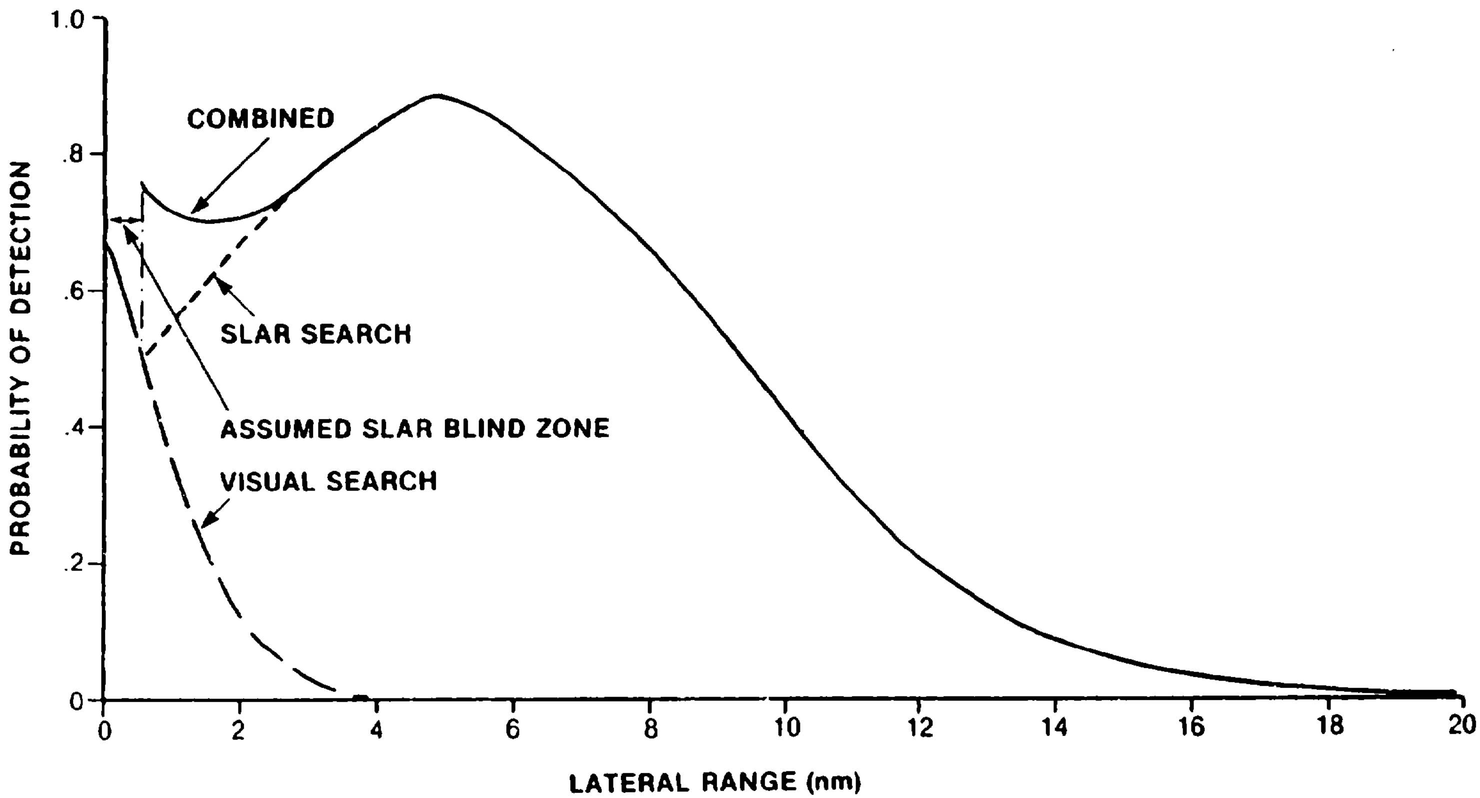


Figure 2-3. AOSS SLAR/Visual Search Performance in Good Conditions; Blue, 16-Foot Fiberglass Boat Target Without Reflective Equipment

When there is an indeterminate amount of correlation between the detection performance achieved by two sensors, an accepted practice (Reference 21) is to average the probabilities obtained assuming complete independence (given above) and complete correlation to estimate the combined sensor detection probability. When applying an assumption of complete correlation, the combined sensor detection probability is simply the higher of the two individual probabilities.

As mentioned in Section 1.4.1, the independence assumption was applied when calculating both SLAR/visual and SVR/visual lateral range curves, and a second set of SVR/visual lateral range curves was generated using the averaging method.

All lateral range curve ordinates were generated using the two methods described above. Lateral range increments of 0.01 to 0.5 nautical miles were used, depending on data availability.

1.4.4 Sweep Width Calculations

Sweep width, as defined in Section 1.2, is the area under a lateral range curve that represents the search craft's detection performance in a specific set of circumstances. The combined sensor lateral range curves generated in this analysis cannot be expressed in the form of a mathematical function; thus, corresponding sweep widths were obtained using numerical integration. Simpson's First Rule for approximate integration was used for these calculations. Using this technique, sweep width is given by the expression

$$W = 2 \frac{\Delta x}{3} \left(P_1 + 4P_2 + 2P_3 + 4P_4 + \ldots + P_n\right)$$

where P_n denotes the n^{th} equally spaced probability ordinate on the lateral range curve and Δx denotes the ordinate spacing in nautical miles. The multiplier of 2 is used so that only one side of the lateral range curve (which is assumed symmetric to both sides of the search craft) need be integrated.

SLAR/visual calculations used a Δx of 0.5 nautical miles; SVR/visual calculations utilized a Δx of 0.01 nautical miles for extrapolated curves (generated mathematically) and 0.1 nautical miles for curves generated from empirical data.

1.4.5 FLIR Videotape Analysis

The objective of the FLIR videotape analysis was to determine what differences, if any, existed between real-time operational detection performance of the FLIR operator and the actual display on the FLIR video screen. Factors that could potentially reduce the FLIR operator's target detection performance in real time (for example, screen glare, distractions, fatigue, and individual perceptual limitations) were eliminated in the post-experiment videotape analysis, or "perfect" search. Not eliminated were factors that would degrade performance in detecting valid targets due to operating errors. These included poor focus/gain adjustment of the FLIR display and any deviations from the assumed field of view.

The "perfect" search as defined was attained by having a team of analysts watch the available tapes. The team listened to the videotape sound tracks for cues on the presence of targets and was allowed to back up and replay tapes to attempt earlier detections than those achieved by the FLIR operators. The team also attempted to detect targets missed completely in real time.

Time differences between post-analysis search team detections and real time detections were noted along with independent post-analysis detections. The results of this analysis are presented in Chapter 3.

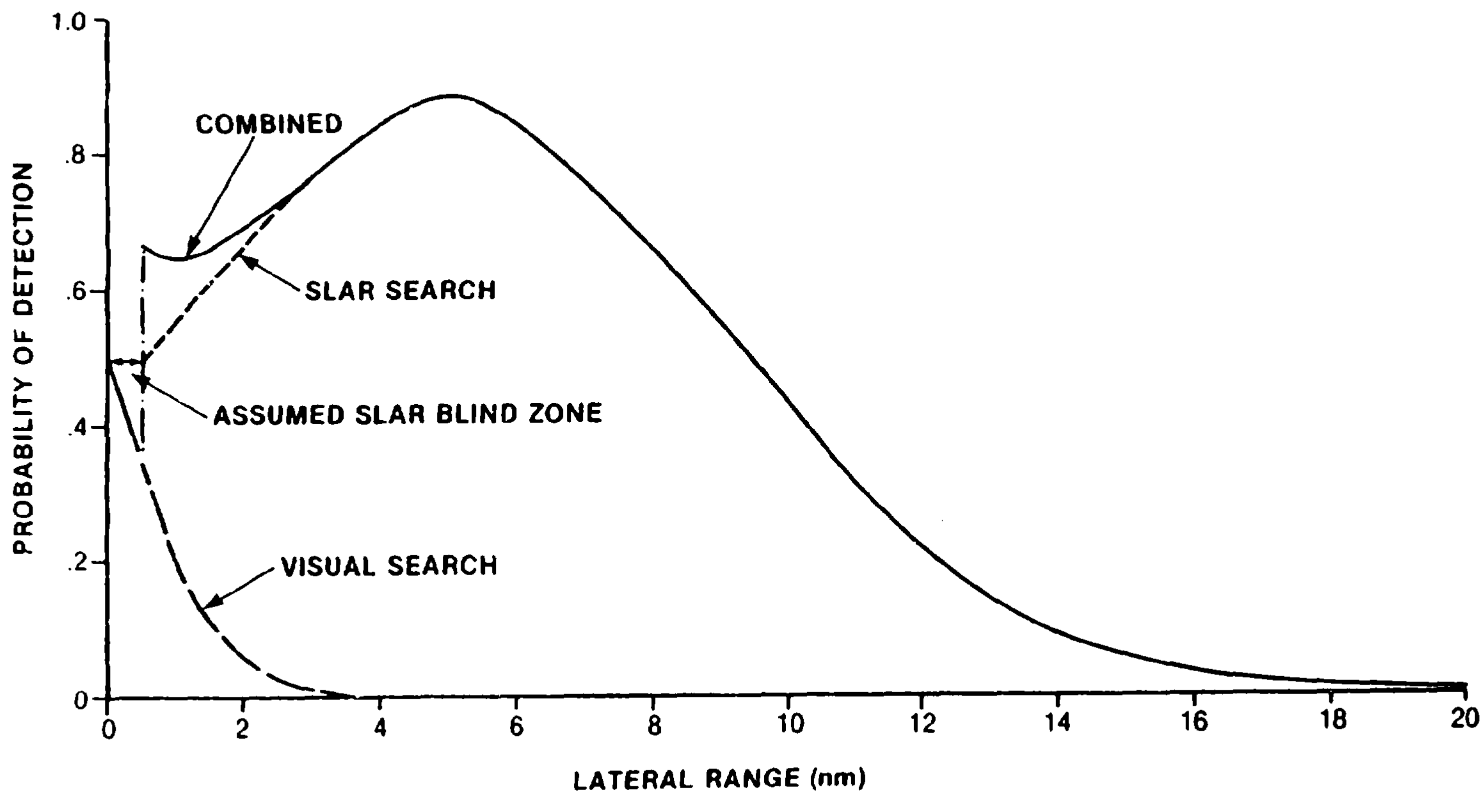


Figure 2-4. AOSS SLAR/Visual Search Performance in Fair Conditions; Blue, 16-Foot Fiberglass Boat Target Without Reflective Equipment

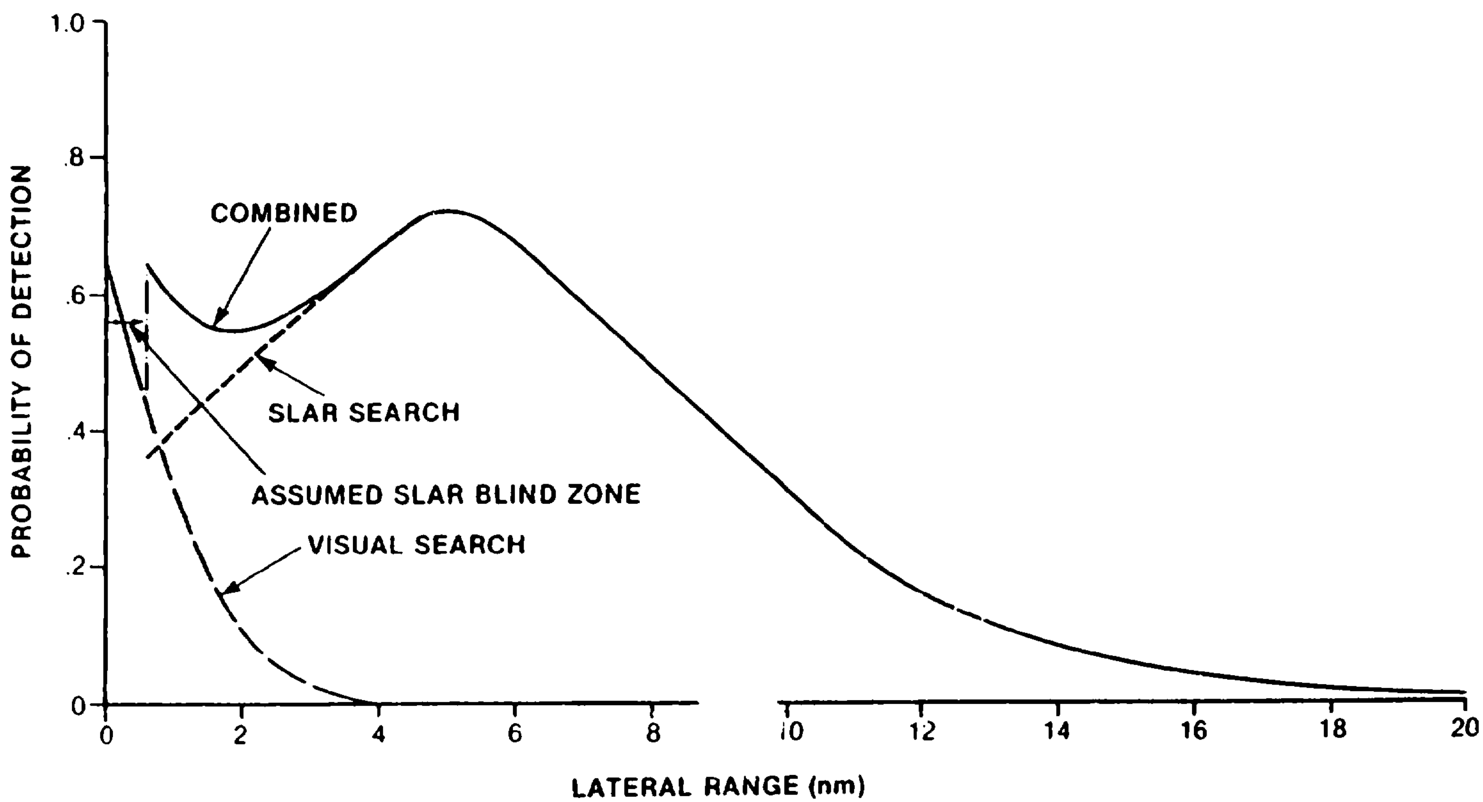


Figure 2-5. AOSS SLAR/Visual Search Performance in Good Conditions; Black, 7-Man Life Raft Target Without Radar Reflector

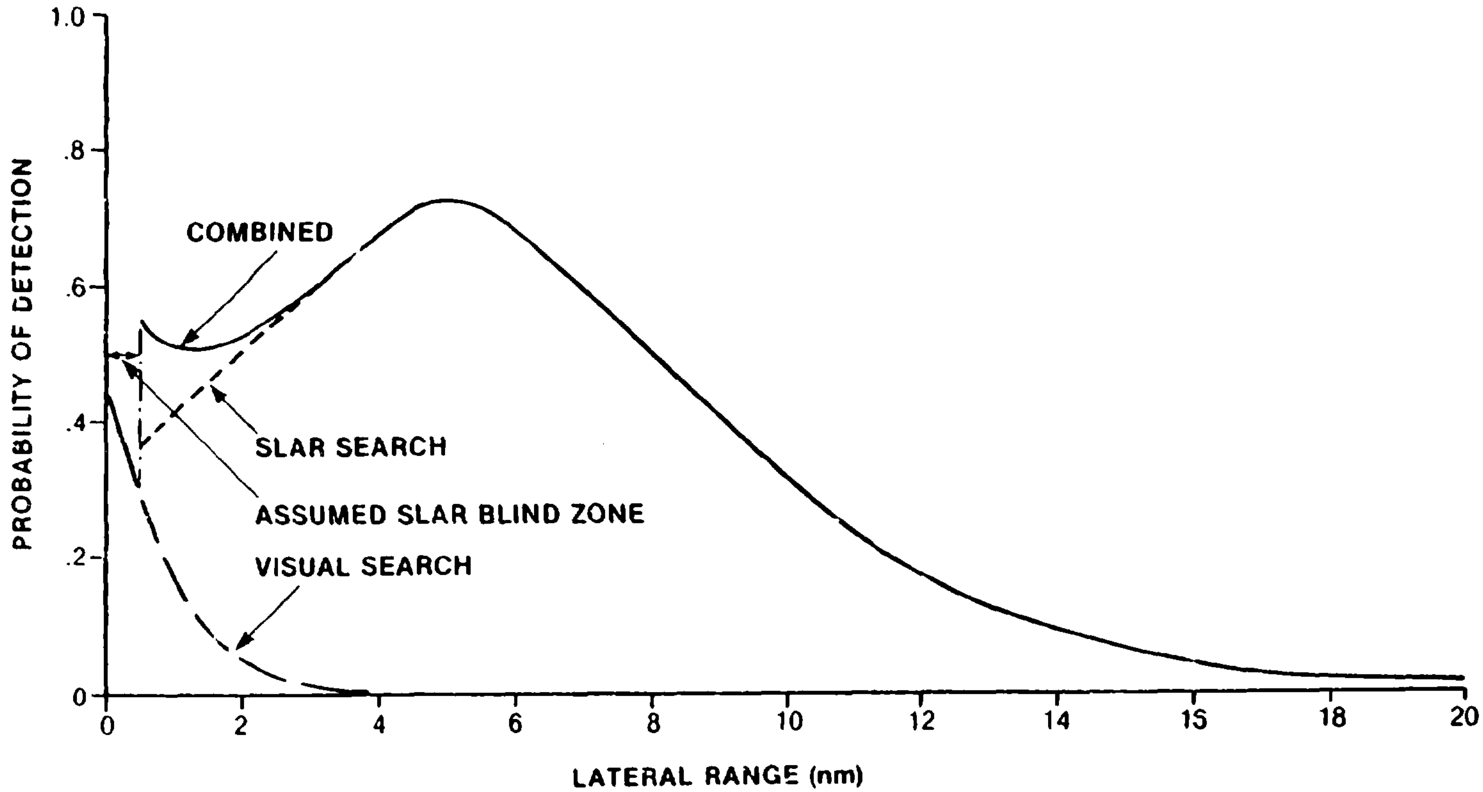


Figure 2-6. AOSS SLAR/Visual Search Performance in Fair Conditions; Black, 7-Man Life Raft Target Without Radar Reflector

Parameter	Good Conditions	Fair Conditions
Wind Speed (knots)	≤ 8	15
Significant Wave Height (ft)	0.5	2
Visibility (nm)	≥ 10	5
Cloud Cover (%)	50	100
Time on Task (hr)	2	2
Search Speed (knots)	200	200
Search Altitude (ft)	2000	2000

Three target types were assumed:

- o White, 16- to 21-foot fiberglass boat with engine, gas tank, seats, etc., ("fully equipped"),
- o Blue, 16-foot fiberglass boat without significant metal equipment, and
- o Black, 7-man life raft without canopy or radar reflector.

Search altitude and target type are the parameters that most affect SLAR search performance over this range of conditions, while all parameters listed except altitude are significant in defining visual detection performance. The 2000-foot altitude is recommended in Reference 6 as best for AOSS SLAR searches and is within the range of acceptable values for visual search in clear weather given in Reference 8. The 200-knot search speed was chosen as a compromise between maximum search speed (desirable for SLAR) and lower search speeds favored for visual searches.

It is evident from Figures 2-1 through 2-6 that visual search effectively supplements the SLAR coverage by filling in a "blind zone" underneath and immediately adjacent to the aircraft's search track caused by the antenna pattern and heavy sea return. This zone was assumed to be about 0.5 nautical miles to either side of the aircraft based on available experiment data. From 0.5 to about 3 nautical miles, visual search enhances SLAR performance by progressively smaller amounts. Table 2-1 contains sweep widths for each of the six lateral range curves shown in the figures. These sweep-width values,

while only 5 to 8 percent higher than the AOSS SLAR values given in References 6 and 10*, reflect this added search area coverage.

Table 2-1. Sweep Widths (in Nautical Miles) for Combined AOSS SLAR/Visual Searches

TARGET TYPE	ENVIRONMENTAL CONDITIONS*	
	GOOD	FAIR
High-contrast (e.g., white), 16- to 21-foot fiberglass or aluminum boat with engine and/or other metal equipment	22.0	21.8
Medium-contrast (e.g., blue), 16-foot fiberglass boat without engine or other metal equipment	17.1	16.8
Black life raft without metal equipment or canopy	13.7	13.3
*"Good" and "Fair" environmental conditions were defined in the preceding text.		

2.2.2 Recommendations for SLAR/Visual Search

In planning a SLAR/visual search, some compromises may be necessary when selecting controllable search parameters such as speed or altitude. Since the SLAR sensor will cover most of the area to be searched, search speed and altitude generally should be selected for optimum SLAR performance. SLAR detection performance is not affected by aircraft speed; thus, search speed should be as high as possible for the existing conditions to maximize the rate of search effort allocation (sweep width times trackline miles). Visual detection performance was shown in Reference 8 to deteriorate somewhat at speeds above 120 knots, but the loss in the rate of search effort allocation is minimal when higher speeds are used. AOSS SLAR detection performance with small

*In Reference 6, tables labeled "sweep width" actually contain half sweep-widths (to one side of the aircraft only). This error was corrected in Reference 10.

targets was shown in Reference 6 to be very sensitive to search altitude, with 2000 to 3000 feet preferred. These altitudes are well within the range recommended in Reference 8 for visual search in clear weather, but may result in degraded visual detection performance in poor visibility conditions. The loss in SLAR performance that would result from searching at altitudes below 2000 feet would normally outweigh the reduced visual detection performance, however, and doing so is not recommended.

2.3 SVR/VISUAL SEARCH PERFORMANCE

2.3.1 Lateral Range Curves and Sweep Widths

A total of 81 cases of SVR/visual search were analyzed using both empirical and extrapolated detection performance data. Search parameter values associated with each weather-condition category analyzed are listed in Table 2-2. Figures 2-7 through 2-10 are four examples of the estimated combined sensor lateral range curves obtained. Tables 2-3 through 2-6 present two sweep width estimates for each case analyzed, one calculated assuming completely independent sensors, and one calculated by averaging the sweep width obtained assuming complete independence with that obtained assuming perfect correlation between sensors.

2.3.1.1 AN/SPS-66 Radar

Two example sets of lateral range curves for the AN/SPS-66 radar augmenting visual search are given in Figures 2-7 and 2-8. Figure 2-7 represents a search scenario in which the radar contributes a significant portion of the search platforms's detection capability. This is due to favorable radar weather (see search parameters listed on the figures) and the presence of a radar reflector on the target. Visual search conditions are also favorable with a medium-contrast target. Under these circumstances, the AN/SPS-66 radar makes almost all of its contribution to sweep width inside 2 nautical

Table 2-2. Search Parameter Values Used in Developing SVR/Visual Lateral Range Curves

SEARCH PARAMETER	WEATHER CONDITIONS						
	GOOD	FAIR	LIGHT RAIN	MODERATE RAIN	HEAVY RAIN	MODERATELY HEAVY SNOW @ 0°C	DENSE FOG† @ 15°C
Wind Speed (knots)*	≤8	20	≤8	10	15	15	N/A
Significant Wave Height (ft)	0.5	3	0.5	1	2	2	≤2
Time on Task (hr)*	2	2	2	2	2	2	N/A
Visibility (nm)*	10	5	5	3	1	0.5	100 ft
Cloud Cover (%)*	0	50	100	100	100	100	N/A
Precipitation**	None	None	1 mm/hr	4 mm/hr	16 mm/hr	4 mm/hr of water; 1.5 in./hr of wet snow	fog

*Used in visual detection model only
**Used in radar detection model only
†No visual contribution to sweep width assumed

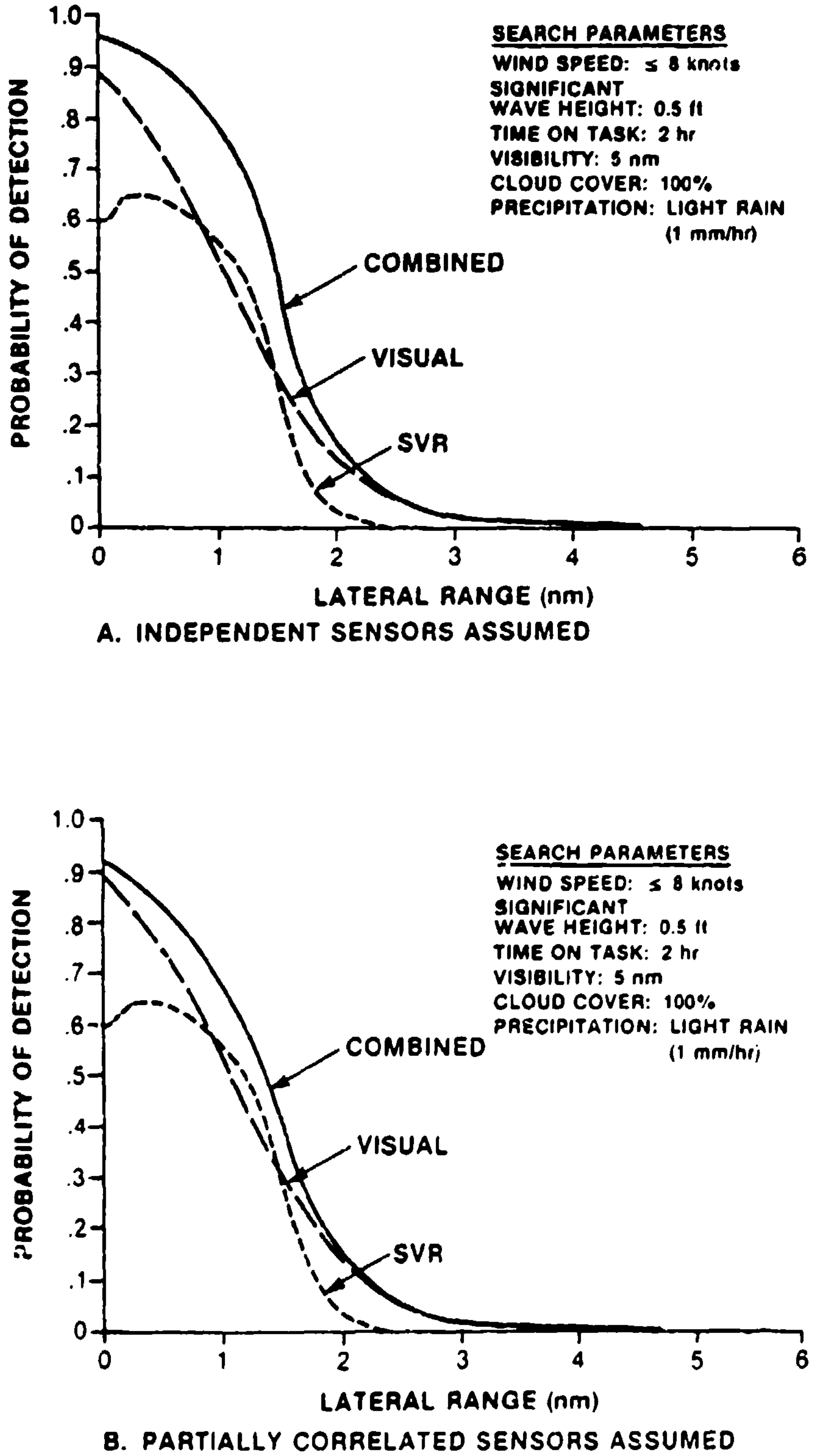
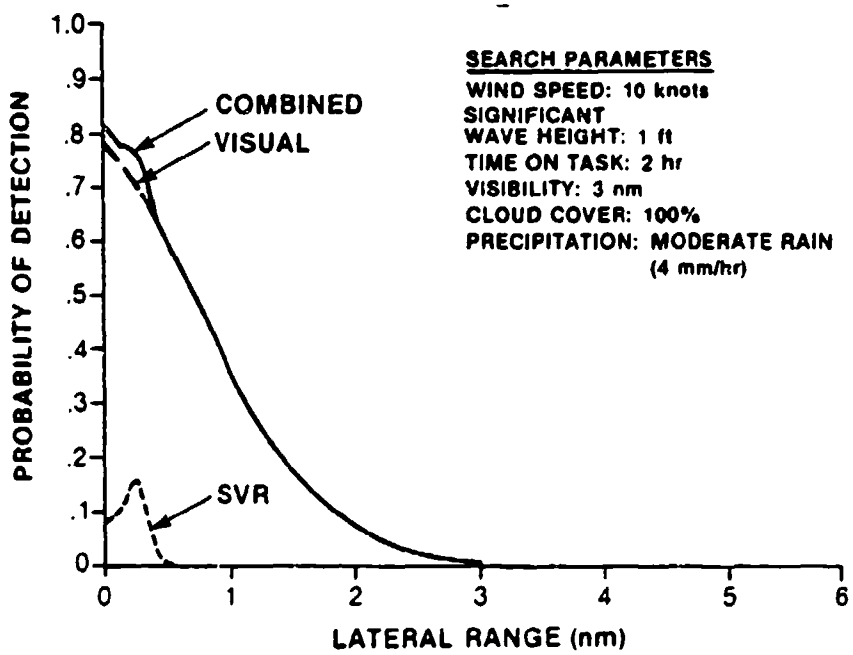
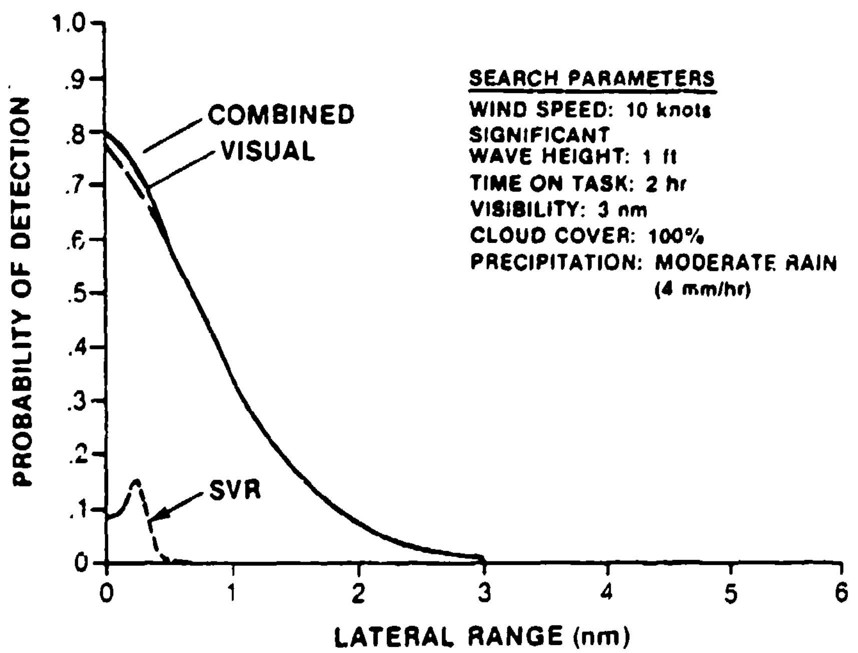


Figure 2-7. Combined AN/SPS-66 Radar/Visual Detection Performance; Blue, 16-Foot Boat Target With Radar Reflector

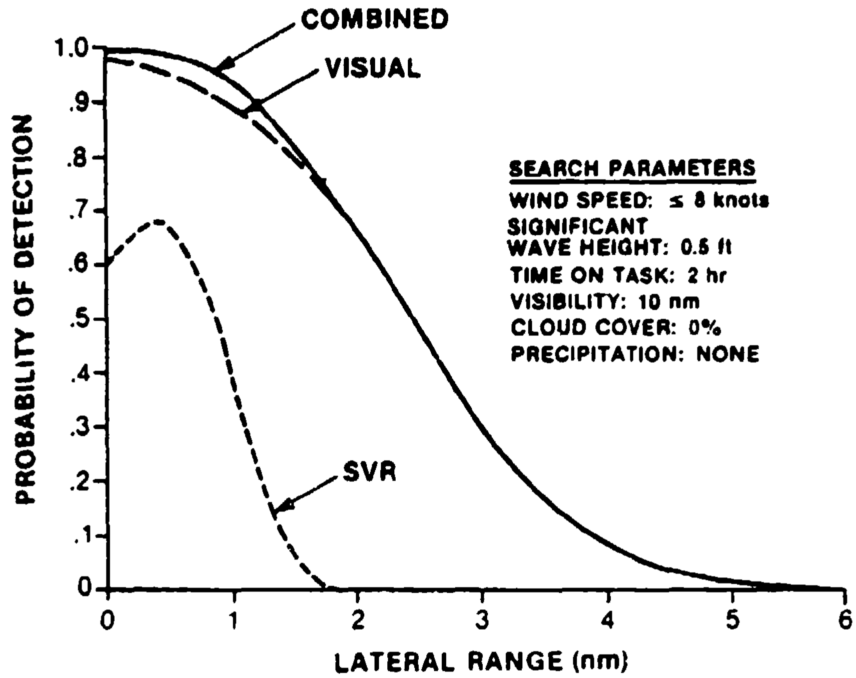


A. INDEPENDENT SENSORS ASSUMED

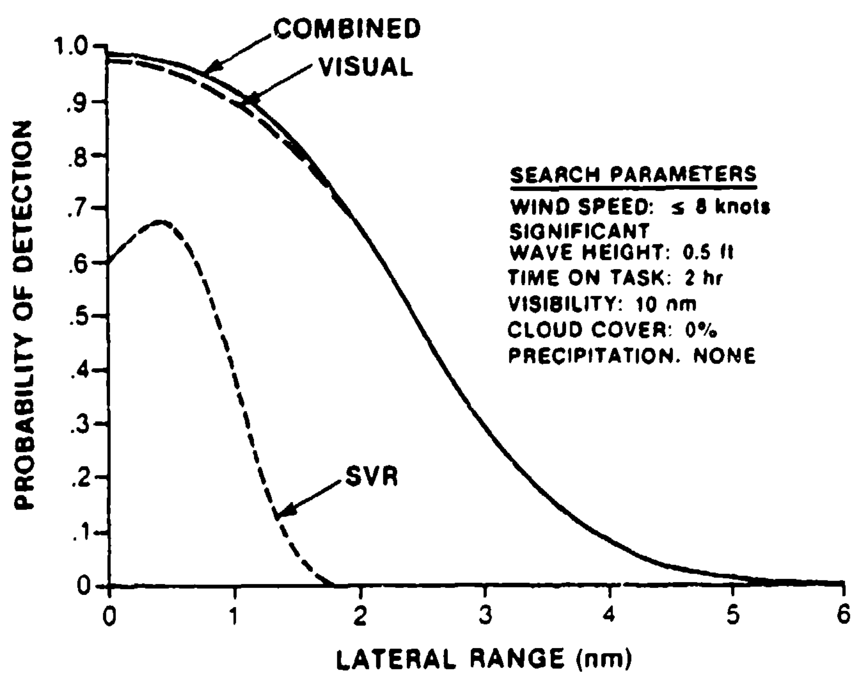


B. PARTIALLY CORRELATED SENSORS ASSUMED

Figure 2-8. Combined AN/SPS-66 Radar/Visual Detection Performance; Blue, 16-Foot Boat Target Without Radar Reflector

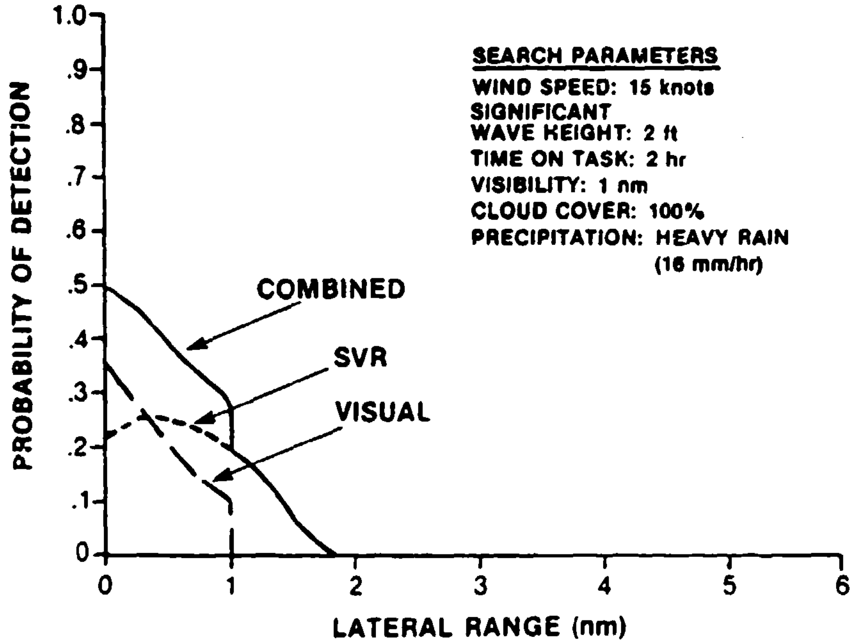


A. INDEPENDENT SENSORS ASSUMED

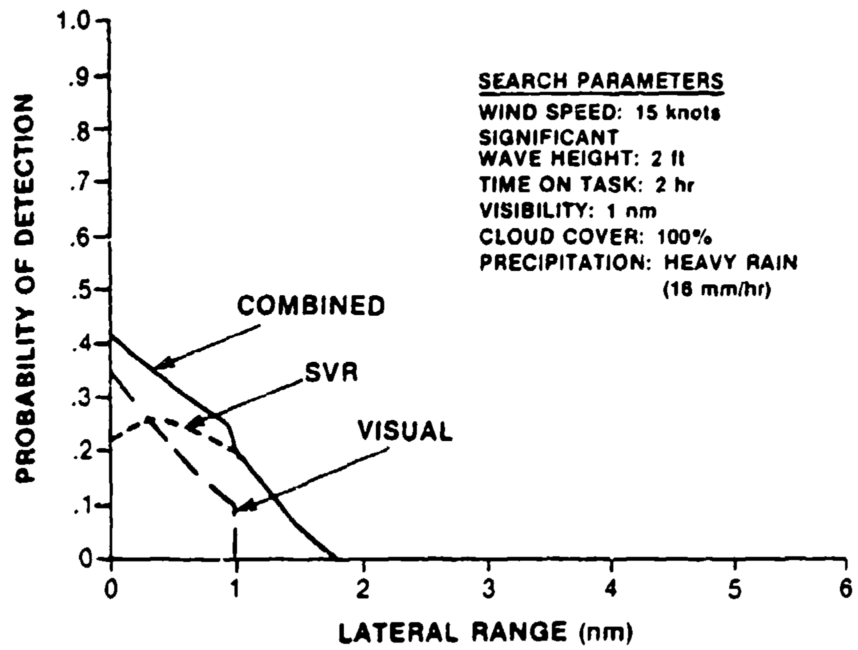


B. PARTIALLY CORRELATED SENSORS ASSUMED

Figure 2-9. Combined AN/SPS-64(V) Radar/Visual Detection Performance; White, 16-Foot Boat Target Without Radar Reflector



A. INDEPENDENT SENSORS ASSUMED



B. PARTIALLY CORRELATED SENSORS ASSUMED

Figure 2-10. Combined AN/SPS-64(V) Radar/Visual Detection Performance; White, 16-Foot Boat Target With Radar Reflector

Table 2-3. Combined Radar/Visual Sweep Widths for AN/SPS-66 Radar Aboard 41-Foot UTBs (Targets With Radar Reflectors)

ENVIRONMENTAL CONDITIONS	WHITE, 16-FOOT BOAT OR ORANGE LIFE RAFT WITH CANOPY	BLUE, 16-FOOT BOAT OR ORANGE LIFE RAFT WITHOUT CANOPY	BLACK LIFE RAFT WITHOUT CANOPY
Good Weather 0.5-ft Seas	3.8 / 3.6	3.4 / 3.2	3.2 / 3.0
Fair Weather 3-ft Seas	1.2 / 1.1	0.9 / 0.8	0.8 / 0.7
Light Rain (1mm/hr) 0.5-ft Seas	3.2 / 3.0	2.9 / 2.6	2.8 / 2.5
Moderate Rain (4mm/hr) 1-ft Seas	2.3 / 2.2	1.9 / 1.8	1.8 / 1.6
Heavy Rain (16mm/hr) 2-ft Seas	0.9 / 0.8	0.8 / 0.7	0.7 / 0.6
Moderately Heavy Snow (@ 0°C) (4mm/hr of water) 2-ft Seas	0.7 / 0.7	0.7 / 0.6	0.7 / 0.6
Dense Fog (100-ft visibility @ 15°C) 0.5-ft Seas	1.9 / 1.9	1.9 / 1.9	1.9 / 1.9

NOTE: Numbers in each box are sweep widths obtained assuming independent/partially correlated sensor performance. Sweep widths are rounded to nearest 0.1 nm.

Table 2-4. Combined Radar/Visual Sweep Widths for AN/SPS-66 Radar Aboard 41-Foot UTBs (Targets Without Radar Reflectors)

ENVIRONMENTAL CONDITIONS	WHITE, 16-FOOT BOAT OR ORANGE LIFE RAFT WITH CANOPY	BLUE, 16-FOOT BOAT OR ORANGE LIFE RAFT WITHOUT CANOPY	BLACK LIFE RAFT WITHOUT CANOPY
Good Weather 0.5-ft Seas	3.6 / 3.5	3.1 / 3.0	3.0 / 2.9
Fair Weather 3-ft Seas	--* / --*	--* / --*	--* / --*
Light Rain (1mm/hr) 0.5-ft Seas	2.8 / 2.7	2.3 / 2.3	2.1 / 2.1
Moderate Rain (4mm/hr) 1-ft Seas	2.1 / 2.1	1.6 / 1.6	1.5 / 1.4
Heavy Rain (16mm/hr) 2-ft Seas	0.5 / 0.4	0.3 / 0.3	0.3 / 0.3
Moderately Heavy Snow (@ 0°C) (4mm/hr of water) 2-ft Seas	0.3 / 0.2	0.2 / 0.2	0.2 / 0.1
Dense Fog (100-ft visibility @ 15°C) 0.5-ft Seas	0.4 / 0.4	0.4 / 0.4	0.4 / 0.4

NOTE: Numbers in each box are sweep widths obtained assuming independent/partially correlated sensor performance. Sweep widths are rounded to nearest 0.1 nm.

*The AN/SPS-66 radar was unable to detect targets without reflectors in these conditions.

Table 2-5. Combined Radar/Visual Sweep Widths for AN/SPS-64(V) Radar Aboard 82-Foot WPBs (Targets With Radar Reflectors)

ENVIRONMENTAL CONDITIONS	WHITE, 16-FOOT BOAT OR ORANGE LIFE RAFT WITH CANOPY	BLUE, 16-FOOT BOAT OR ORANGE LIFE RAFT WITHOUT CANOPY	BLACK LIFE RAFT WITHOUT CANOPY
Good Weather 0.5-ft Seas	5.9 / 5.5	5.5 / 5.1	5.5 / 5.1
Fair Weather 3-ft Seas	1.9 / 1.7	1.8 / 1.6	1.7 / 1.6
Light Rain (1mm/hr) 0.5-ft Seas	4.7 / 4.3	4.4 / 4.1	4.2 / 3.9
Moderate Rain (4mm/hr) 1-ft Seas	2.8 / 2.5	2.5 / 2.2	2.4 / 2.2
Heavy Rain (16mm/hr) 2-ft Seas	0.9 / 0.8	0.8 / 0.7	0.8 / 0.7
Moderately Heavy Snow (@ 0°C) (4mm/hr of water) 2-ft Seas	1.8 / 1.7	1.7 / 1.7	1.7 / 1.7
Dense Fog (100-ft visibility @ 15°C) 0.5-ft Seas	3.6 / 3.6	3.6 / 3.6	3.6 / 3.6

NOTE: Numbers in each box are sweep widths obtained assuming independent/partially correlated sensor performance. Sweep widths are rounded to nearest 0.1 nm.

Table 2-6. Combined Radar/Visual Sweep Widths for AN/SPS-64(V) Radar Aboard 82-Foot WPBs (Targets Without Radar Reflectors)

ENVIRONMENTAL CONDITIONS	WHITE, 16-FOOT BOAT OR ORANGE LIFE RAFT WITH CANOPY	BLUE, 16-FOOT BOAT OR ORANGE LIFE RAFT WITHOUT CANOPY	BLACK LIFE RAFT WITHOUT CANOPY
Good Weather 0.5-ft Seas	5.0 / 4.9	4.4 / 4.3	4.2 / 4.1
Fair Weather 3-ft Seas	1.5 / 1.3	1.3 / 1.2	1.3 / 1.2
Light Rain (1mm/hr) 0.5-ft Seas	3.4 / 3.3	2.8 / 2.7	2.6 / 2.6
Moderate Rain (4mm/hr) 1-ft Seas	2.1 / 2.1	1.6 / 1.6	1.5 / 1.4
Heavy Rain (16mm/hr) 2-ft Seas	0.5 / 0.4	0.3 / 0.3	0.3 / 0.3
Moderately Heavy Snow (@ 0°C) (4mm/hr of water) 2-ft Seas	0.3 / 0.3	0.3 / 0.2	0.2 / 0.2
Dense Fog (100-ft visibility @ 15°C) 0.5-ft Seas	0.8 / 0.8	0.8 / 0.8	0.8 / 0.8

NOTE: Numbers in each box are sweep widths obtained assuming independent/partially correlated sensor performance. Sweep widths are rounded to nearest 0.1 nm.

miles, while visual detection is possible out to about 3 nautical miles. If environmental conditions deteriorate to those listed on Figure 2-8 and the radar reflector is removed from the target, a dramatic change results. The radar contribution to sweep width is almost completely eliminated in this case, reducing sweep width to about that achievable with visual search alone.

The reader will note from Tables 2-3 and 2-4 that predicted sweep width is dependent upon the assumption made concerning sensor correlation only in the first case because both sensors make a significant contribution to sweep width. When one sensor represents most of the platform's detection capability, assumptions concerning sensor correlation become inconsequential. Visual detection generally dominates when visibility is good and the target is without a radar reflector, while radar dominates when visibility is poor (snow or dense fog) and the target has a radar reflector. Search units would benefit by familiarizing themselves with the conditions that favor a particular sensor and conducting searches in a manner favoring that sensor.

2.3.1.2 AN/SPS-64(V) Radar

Figure 2-9 presents example lateral range curves for conditions favorable to both radar and visual search. A white, 16-foot boat target without a radar reflector is assumed. In this example, the visual search lateral range curve is above 85 percent probability of detection for almost the entire range of radar capability, resulting in only a small improvement over visual sweep width due to the radar contribution.

Figure 2-10 depicts an example of combined sensor detection performance in severely degraded weather conditions. In this case, the search target is a white, 16-foot boat with a radar reflector. Poor visibility and the presence of a radar reflector slightly favor the AN/SPS-64(V) over visual scanners. Inside 1 nautical mile, both sensors make similar contributions to sweep width, while radar alone contributes beyond that lateral range.

Comparison of sweep widths in Tables 2-5 and 2-6 with those in Tables 2-3 and 2-4 indicates that, for all cases analyzed, cutters equipped with the AN/SPS-64(V) radar achieve sweep widths ranging from the same as to more than twice those predicted for 41-foot UTBs equipped with the AN/SPS-66. The magnitude of this advantage depends on the relative sweep width contribution made by radar and prevailing visual search conditions. The AN/SPS-64(V) was shown in Reference 9 to perform much better than the AN/SPS-66; thus, it has a greater potential for making a significant contribution to combined sensor sweep widths (compare, for example, sweep width estimates for moderately heavy snow). While small cutters (WPBs) were shown in Reference 8 to achieve generally better visual detection performance that UTBs, this advantage nearly disappears when visibility drops below 3 nautical miles. This effect manifests itself in the sweep width tables by values which are similar for both units under heavy rain conditions, when visibility is low and radar performance is extremely poor. The reader is cautioned that only limited visual detection data were collected in low-visibility conditions; thus, visual sweep width estimates for these conditions, like extrapolated SVR sweep width estimates, are only approximate.

2.4 RECOMMENDATIONS

Based upon analysis results presented in this chapter, the following recommendations are made:

- Limited field experiments should be conducted to validate the combined sensor sweep width estimates given in this report. A special effort should be made to collect combined sensor search performance data in low visibility/precipitation conditions due to the present lack of both visual and electronic field data of this type.

- Lateral range curves for combined sensor searches should be input to the Coast Guard Computer-Assisted Search Planning (CASP) model (Reference 22) so that base PODs similar to those given in Reference 14 can be generated.

- Sweep width estimates, base PODs, and search conduct guidance for combined sensor searches should be incorporated into the National SAR Manual (Reference 1).

CHAPTER 3
FLIR VIDEOTAPE ANALYSIS

3.1 INTRODUCTION

The FLIR detection tests consisted of four days of PIW searches, three days of boat and life raft searches, and two nights of PIW/boat/life raft searches. Videotapes were successfully recorded for three days of PIW searches and two days of boat/raft searches and problems with the onboard video recorder prevented the recording of any night searches.

3.2 RESULTS

From a total of 167 detection opportunities that occurred during the successfully taped searches, 115 real-time detections and 120 post-analysis detections were made. This difference, however slight, does indicate the existence of performance degradation in real time that can be attributed to the FLIR operator. The 115 targets that were detected in real time were discernible to the post-analysis search team on the video display an average of 4.8 seconds earlier than the FLIR operator had announced them. This translates to an average increase in detection range of just under 0.1 nautical mile at the assigned 60-knot ground speed.

Sorting the data into various swell-height and target-type categories (Table 3-1) suggested that operator degradation was sensitive to these parameters.

3.2.1 Target Type

Sorting the data by target type suggested that no significant operator degradation existed when searching for PIWs. Only one independent post-analysis detection was made out of a total of 78 detections. No substantial time difference in initial detection calls was observed between the FLIR operator and video analysis team.

Table 3-1. Comparison of Real-Time and Post-Analysis FLIR Detection Performance

TARGET TYPE	RANGE OF SIGNIFICANT WAVE HEIGHT (ft)	MEAN SIGNIFICANT WAVE HEIGHT (ft)	REAL TIME		POST-ANALYSIS		NUMBER OF OPPORTUNITIES
			PERCENT OF TARGETS DETECTED (number detected)	MEAN DETECTION RANGE (nm)	PERCENT OF TARGETS DETECTED (number detected)	MEAN DETECTION RANGE (nm)	
BOATS AND RAFTS	≤ 2	0.16	77 (24)	1.04	84 (26)	1.38	31
	>2	2.89	57 (13)	0.51	65 (15)	0.57	23
PIWs	≤ 2	1.08	74 (77)	0.25	75 (78)	0.25	104
	>2	2.78	11 (1)	0.10	11 (1)	0.10	9

With boat and life raft targets operator degradation was more visible. Of the 41 post-analysis detections, 4 were independent. Detection calls averaged 14.6 seconds earlier in post-analysis, with 90 seconds as a maximum.

3.2.2 Significant Wave Height

Sorting results of boat and life raft searches by significant wave height (hereafter referred to as "wave height") indicated only that earlier (longer range) post-analysis detections were more likely to be made when the search was conducted in seas under 2 feet. Results for independent detection in post-analysis suggest no significant difference due to wave height (two independent post-analysis detections were made in each wave-height category).

3.3 CONCLUSIONS

Some detection performance degradation attributable to the FLIR operator existed during the experiment. This degradation was observable in boat and life raft searches only. PIW searches were a faster-paced type of exercise (targets were closer together on short search legs), thus diminishing the chances for fatigue and boredom to degrade operator performance. The search performance differences discussed in Section 3.2.1, therefore, probably resulted from the structure of the exercises rather than from the target type involved. Grouping of the data by significant wave height indicated that a longer FLIR detection range capability in low wave-height conditions exists than was achieved in real time. However, chances of ultimately detecting the target were not substantially improved by post-analysis of videotapes recorded in either wave-height category.

The data upon which these conclusions are based are extremely limited in scope; only three real-time FLIR operators are represented in the videotaped searches. Additional data should be collected using a variety of FLIR operators if reliable estimates of performance degradation due to human factors are desired.

3.4 RECOMMENDATIONS

If additional investigation of human factors in the FLIR detection process is conducted, the following should be considered:

- Include time on task as a parameter in the analysis of operator performance. One would expect time on task to have a negative influence on FLIR operator performance based upon previous Project-related work (Reference 8).

- Ensure that a broad variety of environmental conditions and FLIR operators are represented in the data. This would best be achieved by rotating FLIR operators during each search day.

- Provide a uniform amount of training and practice time with the FLIR system to each operator before data collection.

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